

## Semi-annual Eos Contract Report -- Report #42

Period: January 1 -June 30, 1995

Remote Sensing Group (RSG), Optical Sciences Center (OSC) at the University of Arizona

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Contract Number: NAS5-31717

Report compiled by: K. Thome



**Summary:** Work by members of the RSG during the past six months consisted of Science Team support activities including the submission of several calibration papers, attendance at meetings related to MODIS, SeaWiFS, and MISR, work on the atmospheric correction of ASTER data, and assisting in a stray light study for MODIS. We continued improvements to our calibration facilities and blacklab including characterization of our Optronic monochromator, field radiometer FOV studies, receipt of a clean bench, and work to automate our blacklab measurements. Field work activities were continued with trips to White Sands and Lake Tahoe in April and a trip to Ivanpah Playa and Lake Tahoe in June. The June trip marked the inaugural use of the mobile laboratory. Work continued on developing the BRDF and diffuse-to-global meters and improving our existing field equipment.

**Introduction:** This report contains twelve sections. The first ten sections present different aspects of work performed under our contract. If appropriate, each section covers five areas; task objective, work accomplished, data/analysis/interpretations, anticipated future actions, and problems/corrective actions. The ten sections are: 1) Science team support activities; 2) Cross-calibration radiometers; 3) TIR field radiometer; 4) Mobile laboratory; 5) Shortwave infrared (SWIR) spectroradiometer; 6) Bi-directional reflectance distribution function (BRDF) meter; 7) Diffuse-to-global meter; 8) Calibration laboratory; 9) Algorithm and code development; and 10) Field experiments. The eleventh section contains information related to faculty, staff, and students, and the twelfth section summarizes papers published, submitted, and in preparation.

**Science Team Support Activities:** This section refers to all work performed in support of MODIS and ASTER team activities as well as work performed for other sensor teams. Over the

past six months this included the attendance at team and other related meetings and completing assigned action items.

*ASTER Activities:* P. Slater and K. Thome completed the first draft of a paper titled “Radiometric calibration of ASTER data” and submitted it to the Journal of Remote Sensing of Japan. The paper is coauthored by K. Arai H. Fujisada, H. Kieffer, A. One, F. Sakuma, F. Palluconi, and Y. Yamaguchi and has been accepted for publication. On January 25, Thome met with B. Eng of JPL to discuss the database requirements for the atmospheric correction and with G. Geller, J. Martonchik, and F. Palluconi (all of JPL) to discuss MISR aerosol products. On January 27, Thome met with J. Conel, M. Helmlinger, S. Hook, A. Kahle, A. Morrison, Palluconi and J. Schioldge to discuss a collaborative TIR calibration campaign at Lake Tahoe in April. On February 3, Slater attended an ASTER/Landsat meeting in Washington, D. C. and gave a presentation on vicarious calibration. P. Spyak performed some preliminary analyses and studies of the contamination requirements for ASTER and sent comments to F. Palluconi of JPL.

S. Biggar, Slater, Spyak, and Thome attended the ASTER Science Team meeting in Flagstaff held the week of May 22. Slater co-chaired the calibration working group meetings. The main issues discussed were joint vicarious calibration campaigns, the results of the ASTER EM tests, and the optimal way to combine different calibration values to produce the most accurate coefficients as a function of time. Biggar and Slater also discussed the generation of the calibration coefficients with Arai and Sakuma. Biggar presented his and Slater’s work from the Journal of Atmospheric and Ocean Technology (JAOTech) paper on calibration coefficient generation from multiple sources described in a later section. Biggar gave Sakuma modified Japan cross-calibration results based on new filter transmittance measurements (see VNIR cross-calibration radiometer section for further details on this). Slater also presented the vicarious calibration/validation plans of the calibration working group to the higher-level-data-products working group. Thome presented two talks to the atmospheric correction working group on test-data plans for the atmospheric correction in the solar reflective and RSG activities at the TIMS Lake Tahoe deployment. Prior to the meeting, Thome met in Tucson with D. Case of ECS and showed him the RSG’s facilities.

*MODIS Activities:* On 2 February, Slater met with B. Guenther and other members of MCST to discuss scan-mirror reflectance change with angle and other concerns. Slater also

attended the MODIS Technical Team meeting. On February 28, he had further meetings with MCST personnel discussing MTF measurements and stray light.

Spyak travelled to SBRC in January to observe near-field scatter measurements for MODIS. Problems with software, electronics, offsets and gains, and charge subtraction prevented him from observing the tests. C. Thompson (SBRC) described test design and procedures, and Spyak toured the high bay and test setup. G. Godden (MCST) and Spyak pointed out that overfilling the ScMA mirror may lead to significant stray light problems in the measurements and that the tests yield little track direction information. They suggested a test to provide this information. Spyak reviewed BRDF data with T. Kampe and Godden and the aft optic's BTDF measurements with Godden. Spyak analyzed the MODIS aft optics scatter data for wavelengths of 0.63, 3.39, and 10.6 micrometers. He reviewed the results with Godden and went to Breault Research Organization, Inc. (BRO) for a teleconference call with Godden, R. Breault (BRO), and D. Milsom (BRO). Spyak reviewed and commented on Godden's paper titled "Notes regarding the scan mirror reflectivity measurement requirements and the proposed SBRC scan mirror reflectivity measurement plan," report number MCST/PAI 95001-A. He analyzed MODIS's scan mirror BRDF data and discussed results of analysis with Godden and Kampe while at SBRC and also in a teleconference with Godden, Kampe, J. Young (SBRC), and Breault and Milsom. Based on these discussions, an agreement was reached on the region of valid data, and how to extrapolate these data to smaller angles. Spyak is concerned that the scatterometers may not have the needed repeatability to make such small-angle scatter measurements and that the illumination spot size may not be large enough to average over a reasonable number of surface spatial frequencies. Kampe is investigating this. As requested by Godden, Spyak reviewed and analyzed BRO's Harvey-Shack fits to the MODIS scatter data. All of the fits were very good, except for the scan mirror fit which badly overestimated the small-angle scatter by roughly a factor of ten for angles less than 0.5 degrees, and significantly overestimated the scatter out to about one degree. Also, the CdTe data were too high by as much as a factor of seven between 0.5 and 1.0 degrees. As a result of scan mirror data error, BRO has redone some of the computations.

Slater chaired the MODIS Calibration Group meeting on May 2 in Greenbelt. He recorded six new action items that were discussed in the MODIS Science Team meeting plenary

session on May 5 (plus three from the Round-table discussion on IR remote sensing). The most important of these was related to the solar-radiation-based calibration (SRBC) of the MODIS SD/SDSM. The present approach, described in ATBD '94, of transferring the preflight calibration to orbit using the SRCA and then calibrating the SD/SDSM with reference to the SRCA, will not meet the requirement for 2% uncertainty in calibration in reflectance, or with respect to the sun. The use of SRBC is the only approach that has been identified that may meet this requirement. Slater chaired the Calibration Round-table discussion on calibration during the MODIS Science Team meeting. The main emphasis was on vicarious calibration and the plans that the EOS Calibration Scientist has with regard to coordinating cross-comparison joint field campaigns, and centralizing the evaluation (and weighting) of different techniques used by different groups. J. Butler and B. Guenther responded to these issues and Slater summarized the discussions in the plenary session on May 5. Discussions of how best to conduct the SRBC at SBRC given the limited time available were continued through May with GSFC personnel.

Biggar, Slater, Spyak attended the MODIS EM Test Data review at SBRC June 13-14 and provided R. Weber a list of concerns, mainly related to calibration. Slater attended the MODIS Level-1B preliminary design review on June 30 and submitted two RIDs related to the flexibility of the software and implementation of changes.

*Other EOS Related Activities:* Biggar and Slater finished the draft of a paper titled "Suggestions for radiometric calibration coefficient generation" and sent it to 35 calibration scientists around the world for comments. It was also submitted to JAOTech and has been accepted for inclusion in a special calibration issue. From 22-24 February, Slater attended the Multisensor Ocean Color Workshop in Miami and participated in the Calibration and Characterization Workshop. On 28 February, he discussed the results of the Workshop with C. McClain and B. Barnes and provided them three pages of comments and suggestions regarding calibration activities for national and international ocean color sensors. The following day he attended the SWAMP meeting. Thome attended the AVIRIS and TIMS Conferences at JPL January 23-24 and January 26. Biggar attended the MISR Cal peer review 27-28 March at JPL and sent comments to S. Reber. Biggar travelled to Ann Arbor, Michigan January 25-28 to make measurements of the calibration units for HYDICE, He also assisted the HYDICE ground crew to set up surface validation targets for the sensor. Biggar and Slater attended a HYDICE meeting

in Tempe on 15 March where Biggar gave a short talk on the measurements made at ERIM in January. Slater attended a CEOS meeting on Ocean Color organized by I. Barton in Lanham on April 30 and May 1. From 10-12 May, Slater attended the CEOS/GCOS meeting held in Arlington on the subject of Calibration/Validation. He presented a paper titled "Sensor requirements for the radiometric consistency of global land-data sets" which emphasizes the problem of realizing accurate radiometry at the pixel level for complex scenes, and that cross-calibration of sensors flying in formation can meet many of the requirements for producing consistent long-term data sets. Spyak attended the IR Calibration Symposium at the University of Utah from May 8- May 11. B. Crowther and M. Brownlee travelled to the Graduate Student Researchers program meetings in Washington, D. C. Crowther presented a poster on the diffuse/global irradiance meter and Brownlee presented a talk on "The Measurement of Angular Reflectance of a Nearly Homogeneous Surface". Biggar attended the EOS IWG in Santa Fe the last week of June.

**Cross-Calibration Radiometers:** This section describes work to design, fabricate, test, and calibrate a set of preflight cross-calibration radiometers (CCRs). These radiometers are to cover the wavelength region from 400 to 2500 nm. To accomplish this, two radiometers will be constructed, each optimized for a specific portion of the spectrum. They will have very low stray light and polarization responses, exhibit sharp, well-defined fields of view and spectral response profiles, and be ultrastable with respect to temperature and time. The radiometers will be used to provide an important independent calibration and cross-calibration of the calibration facilities used by the Phase C/D contractors. The targeted completion date for all of the CCRs is the last quarter of calendar year 1995.

**VNIR CCR:** The objective of this project is to design and build a 400-900 nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer will be compared to NIST-traceable standards of spectral irradiance using pressed PTFE (Halon® or Algorflon) targets. Biggar designed the radiometer with three silicon detectors in a "trap" configuration. Spectral selection is through interference filters and two precision apertures determine the throughput. Heating the detector assembly, filters, apertures, and amplifier to a stabilized temperature, a few degrees above ambient, provides thermal control of

the system. A commercial datalogger digitizes the amplifier output and ancillary information such as detector temperature, and controls the amplifier gain through digital output ports. This datalogger sends the serial digital data to an MS-DOS compatible computer.

Biggar modified the data collection software for the silicon transfer radiometer to speed up the collection cycle using the HP voltmeter instead of the Fluke data logger. He tested the stability of the 6" spherical-integrating source (SIS) used as an "aliveness" check when traveling with the radiometer. A new mount for accurately aligning the radiometer and SIS was designed and built by C. Burkhart. Biggar and S. Reeker shipped the radiometer to Japan and Biggar travelled to Yokohama, Japan February 17-25 to participate in an ASTER/OCTS cross-calibration experiment. The goals of the experiment were to measure NEC's SISs for ASTER and the OCTS using the VNIR transfer radiometer. Other participants in the experiment included J. Butler, the EOS calibration scientist, J. Cooper, a NASA calibration technician, C. Johnson of NIST, F. Sakuma, of NRLM, and various NEC people and observers from JAROS and NASDA. They measured the ASTER (1-meter diameter) SIS on Tuesday and Wednesday and the OCTS (2-meter diameter) SIS on Thursday and Friday. Preliminary study of the measurements indicate NEC's calibrations for the SISs are in general lower than what is indicated by radiometer measurements made by Biggar, NIST, and NRLM with the largest difference reported by NRLM. The GSFC Optronic spectrometer setup has some stray room light problems which made early examination of their measurements problematic.

After returning from Japan, Biggar used the radiometer to view our NIST standard lamp in irradiance mode. B. Nelson started assembly of the new version of the silicon radiometer. The electronics for this version are more robust mechanically, as is the construction of the detector assembly. The circuit designs and optical details are identical to the "prototype". Biggar worked on the software and hardware to prepare the prototype radiometer for use in a light aircraft as part of the SeaWiFS Lake Tahoe and Lunar Lake tests described in the field work section of this report.

Biggar began modifying the radiometer software to use the new powered filter wheel that Nelson is assembling. R. Kingston assembled and tested the electronics related to the automation of the radiometer filter wheel. This included the computer interface, the filter-wheel motor drive, and cable harness which connects the filter wheel to its control circuitry.

**SWIR CCR:** The objective of this project is to design and build a 1000- to 2500-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer will be compared to NIST-traceable standards of spectral irradiance and pressed PTFE (Halon® or Algorflon) targets.

Spyak decided to design the SWIR transfer radiometer around an InSb detector based on discussions of detector and electronics with various vendors, D. Joyce of NOAO at Kitt Peak, and E. Dereniak of the University of Arizona Optical Sciences Center. Linearity, repeatability, and stability will all be limited by electronics, not the detector itself. Spyak worked on the baffle design, customization requirements for the detector/dewar/electronics package, and the bandpass-filter selection. He looked into noise problems associated with unwanted 3 - 6.3 micrometer signal detection. He developed specifications for the cold filter, dewar window and bandpass filters and contacted a variety of filter vendors for review and quotations. He analyzed the thermal rejection requirements, detector mask scatter effects, and tolerancing baffle design. Spyak developed schematic drawings of the radiometer. Spyak worked on the system systems' design with Cincinnati Electronics personnel and defined specifications and tolerancing. He ordered the radiometer detector and its lock-in amplifier. The radiometer package includes detector, amplification electronics, dewar, and cold baffling.

**TIR field radiometer:** The objective of this project is to design and build a field radiometer to cover the 8,000- to 14,500-nm spectral region, test this radiometer, and write control and data acquisition software. This radiometer will be designed for precision only. We hope eventually to build a nearly identical copy of this radiometer for transfer calibration of field blackbodies and that a future version will operate as a transfer radiometer.

J. Walker read applicable literature, began some initial calculations, and defined the instrument and project specifications. He determined a schedule for the project and investigated satellite sensor requirements for the radiometer to bracket the instrument's dynamic range and required sensitivity. Walker developed a spreadsheet to summarize the various sensor specifications for ASTER, ATSR, MODIS, and Landsat TM. The spreadsheet is being used to define the dynamic range and sensitivity requirements for the TIR field radiometer. Included are

calculations of target radiances along with LOWTRAN7 atmospheric path radiances and transmittance results for wavelengths of interest for the above sensors.

**Mobile Laboratory:** The objective of this task is to provide a mobile laboratory for 1) storage and transportation of equipment; 2) electricity (AC and DC) for equipment; and 3) shelter from the sun, heat, and cold for computers and people during measurements and for all of our equipment overnight at experiment sites.

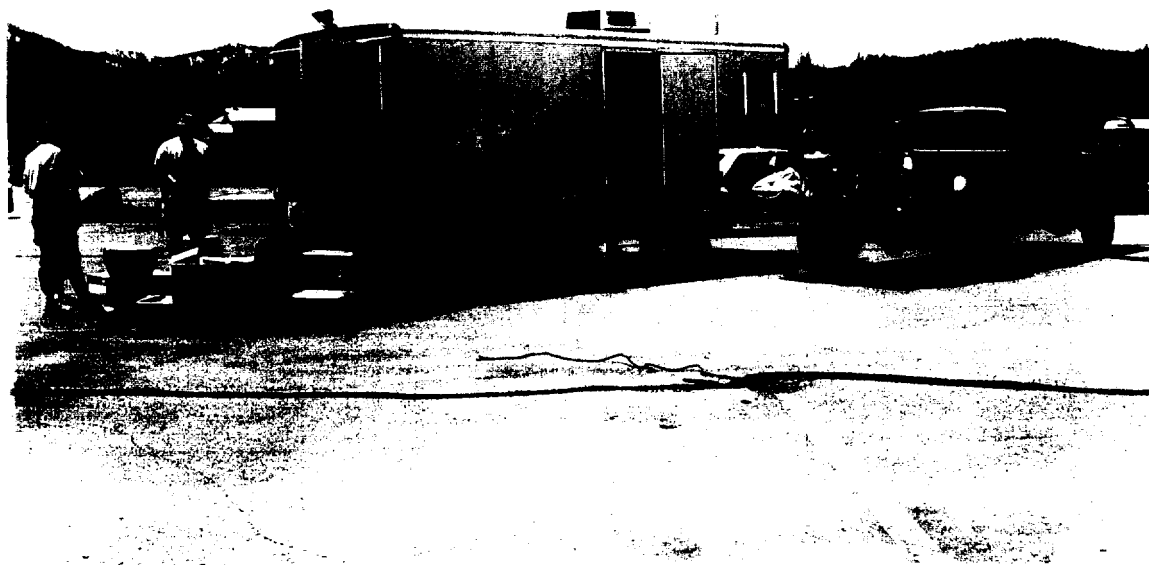
E. Nelson and Spyak weighed our truck and mobile laboratory to help determine the proper location of the fuel tanks for the laboratory's generators. Nelson, with some advice from Biggar, coordinated the purchase of generators for the mobile lab. Nelson and Thome took the trailer to the vendor in Phoenix in March to have the generators installed. The two picked the trailer up the first week in June.

The laboratory was taken on the Ivanpah Playa/Lake Tahoe experiment described in the field trip portion of the report. This was an excellent test for the system, since there are no facilities at Ivanpah Playa and no electrical connections were available at the site used at Lake Tahoe. Figure 1 shows a picture of the truck/trailer combination. The figure shows the two sections of the trailer, a rear section for equipment storage and a front section which is climate controlled and used as work space while at the site. The previously mentioned generators are located in the forward portion of the trailer above the hitch.

The figure also shows the tow vehicle used to transport the trailer. This vehicle performed as hoped by easily towing the system over the rough and sometimes sandy terrain crossed to get to the Ivanpah experiment site. This gives us further confidence that the trailer can be taken to even more remote locations such as Lunar Lake/Railroad Playa.

Future plans for the laboratory include placing shelves in the storage compartment for easier loading of equipment. We also intend to add shelves and permanent storage space in the front section of the laboratory to make on-site work easier in the trailer.

**SWIR solar-spectroradiometer:** The objective of this task is to modify an instrument, originally designed to measure surface reflectance in the SWIR region of the spectrum, to operate as a SWIR solar radiometer. When our contract began, M. Smith had already designed and built



**Figure 1** Remote Sensing Group mobile laboratory and tow vehicle.

the prototype reflectance instrument. Modifications to the original system to increase the signal-to-noise ratio have made the instrument less portable and more difficult to use for surface reflectance measurements. Thome began an effort to use the spectroradiometer as a solar radiometer to extend measurements of atmospheric transmittance into the SWIR.

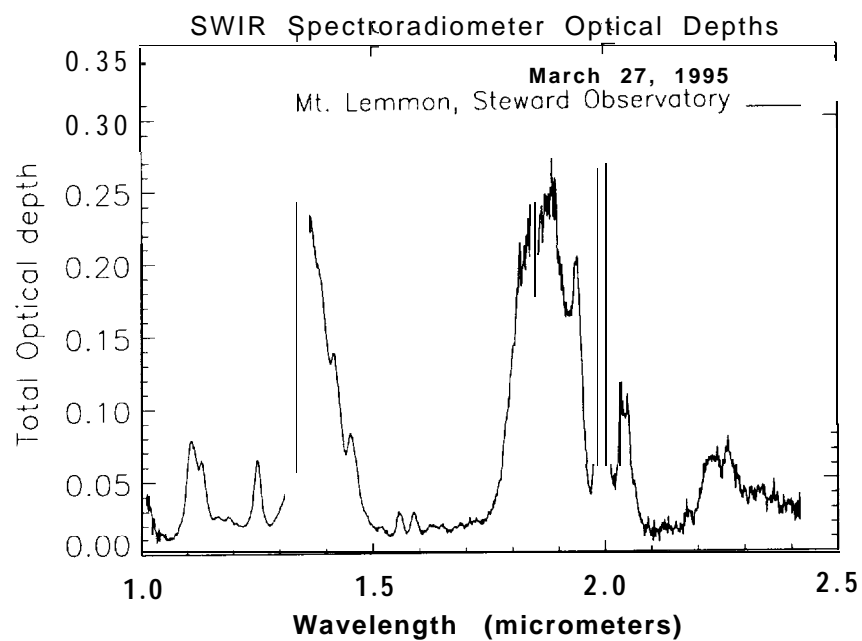
M. Sicard designed a tripod mount for the SWIR spectroradiometer which allows it to be aligned to the sun. C. Burkhart fabricated the v-block mount and pinhole-pointing mechanism based on drawings by Sicard. He determined the neutral-density filter required to prevent the SWIR spectroradiometer from saturating while viewing the sun, and he and Thome travelled to Mt. Lemmon to collect data as part of an effort to calibrate the group's other solar radiometers. Sicard developed processing and visualization software for the data using the IDL software package. Preliminary results of optical depth as a function of wavelength are shown in Figures 2 and 3. These data were collected on Mt. Lemmon and were processed using a Langely-derived calibration to convert the measurement to optical depth. As can be seen by the noise in the data

at longer wavelengths, much work remains to be done, but these preliminary results are very promising. Recently, Sicard modified the SWIR processing software to include a modified Langley approach in water-vapor-absorption spectral regions.

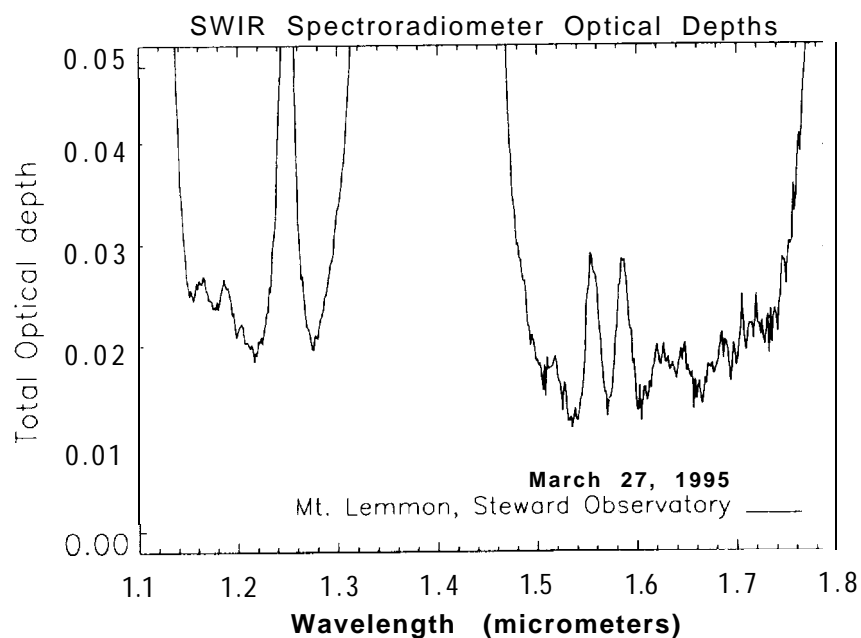
Planned future work includes collecting further data to evaluate the stability of the instrument. We will also examine methods to enhance the signal-to-noise ratio at longer wavelengths to increase the accuracy in this region of the spectrum. The data collection software will be modified to allow larger amounts of data to be collected (currently only 15 scans may be stored before the data must be transferred to another storage device). This software will also be modified to allow signal averaging to increase signal-to-noise. As a last step in this preliminary evaluation, we will study the changes in retrieved aerosol size distribution from including SWIR data into our current inversion scheme.

**BRDF Meter:** The objective for this task is to design and construct a device, and develop software for measuring the directional reflectance and inferring the hi-directional reflectance distribution function of the ground. The basic design incorporates a fisheye lens and a CCD-array detector.

Brownlee completed the carrying cases for the BRDF meter. She completed designs for panel holders for the instrument's Spectralon panels and these were made by the OSC machine shop and have been tested by Brownlee in the blacklab. She completed design of and partially constructed the storage and transportation units for the panels and designed the filter wheel built by Burkhart. Biggar and Brownlee modified blacklab control software to allow reflectance panels to be rotated from vertical. Brownlee continued developing IDL data-display software and examining the effect of reflectance at grazing incidence angles on the predicted radiance at the top of the atmosphere.



**Figure 3** Optical depths derived from SWIR spectroradiometer data collected on Mt. Lemmon.



**Figure 2** Optical depths derived from SWIR spectroradiometer data collected on Mt. Lemmon.

We received a second fisheye lens which will be used in the BRDF instrument. The old lens will be used for all-sky photography on field trips. As part of the April White Sands trip, Brownlee collected and processed BRF data of a selected area of White Sands collected by the instrument known as the “iron maiden.” She made blacklab measurements of the BRDF meter’s reference panels.

Brownlee had the new filter wheel for the BRDF meter exchanged for the existing filter wheel in the Nikor fisheye lens by Tucson Camera Repair. Brownlee processed the blacklab data to retrieve the BRF of the 50% spectralon reflectance panel. The BRF meter was used to examine the 50% panel illuminated by the sun. Results indicate that the panel is spatially non-uniform. Brownlee began testing the spatial uniformity of our 40-inch SIS in preparation for flat-fielding the BRF meter’s CCD-array.

**Diffuse-to-global meter:** The objective of this task is to design and build an instrument to collect diffuse-to-global irradiance data. By comparing the diffuse downwelling irradiance to the global (direct plus diffuse), an improvement to the atmospheric correction may be made which reduces the uncertainty of the reflectance-based method. Currently, global irradiance data are collected using a radiometer viewing a reflectance panel and diffuse data are collected by manually positioning a parasol to shade the panel. The diffuse-to-global meter will collect these data automatically and more repeatably.

Biggar and B. Crowther evaluated various servo and stepper-motor solutions for the instrument. This is still under study and more systems are being evaluated. The desire is for a small, low-power, accurate, system with absolute position encoders. We are also looking for systems that can be powered by batteries if possible. Crowther designed the mechanical components for the semi-kinematic mount used to attach the LI-COR fiber bundle to the blacklab rotation stages. This setup will be used to measure the field of view of the LI-COR fiber bundle, a critical step which must be accomplished before a complete specification of the sphere can be made. A modified version of the mount will be used to attach the fiber to the SIS of the finished diffuse/global irradiance meter. The frame and the mount are awaiting construction. Crowther continued designs for the occulter which have been modeled in three dimensions using AutoCad. The gravity-induced deflection of the occulting disk, when in the

horizontal position, is currently being calculated. Crowther continued the sphere design by completing a three-dimensional-model diagram of a candidate sphere which was sent to Labsphere for review and is awaiting for their comments.

**Calibration Laboratory:** The objective of this project is to develop a calibration laboratory that will provide the necessary high-radiometric-accuracy standards and characterization set-ups for 1) the cross-calibration radiometers and 2) the field and aircraft radiometers needed for preflight algorithm and code validation and the actual in-flight calibration of the EOS multispectral imaging sensors beyond 1998.

During the six-month period we received a filter-wheel motor, lamp-alignment jig, NIST SRM 930E glass filters for calibration of the Optronic, ZEMAX version 4.0 software and manual, long-distance-travel translation stages, an ECPR, a tip-tilt stage, a hemispherical reflectance attachment for the Optronic monochromator, chopper blades for the previously received chopper assembly and motor, lock-in amplifier board, blackbody source, and a kinematic mount, transimpedance amplifier and a temperature/humidity sensor. Spyak sent the multimeter and shunt in for calibration. Burkhart designed and constructed mounts for the new optical breadboard and designed lamp mounting fixtures. Spyak designed a baffle system to surround the lamp and eliminate direct views of the lamp and submitted the plans to Burkhart who constructed the device. Burkhart completed the fabrication of the new radiometer mount, alignment fixtures, lamp stage fixturing, and lamp platform. Burkhart also began developing a system for changing the oil in the blacklab stages without disassembling the entire setup, began modifying the reflectance sample holder to better accommodate samples, and completed the Algoflon holders needed for the NIST measurements.

Spyak made two Algoflon and one HaIon samples and sent them to NIST for spectral hemispherical measurements. He examined crosshair mirror reticles for system alignment. LaMarr realigned the blacklab instrumentation and performed measurements to verify its repeatability with previous measurements. He assembled and tested the water deionizer. Spyak tested our adjustable blackbody for use on the April Lake Tahoe trip described below.

Biggar installed and tested a GPIB interface in the new blacklab PC. LaMarr installed Windows NT on this system and checked that the ZEMAX-EE lens design code runs under NT.

Biggar installed LabView for Sun Solaris on one of our Sun S20s. This will be used to program the lamp, shutter, radiometer, and goniometer control software in the blacklab using an ethernet-GPIB controller. Biggar and R. Kingston worked on porting blacklab software to the laboratory PC system but have encountered problems with the GPIB interface. They began work to allow the HP3245A to control the lamp output via the new blacklab computer.

Spyak and B. Nelson received and assembled the clean bench and accessories for the calibration laboratory,

Optronic returned our repaired monochromator in January. While repairing the system, Optronic found a power drop throughout the unit whenever there was a change in filter or grating position. This would move the chopper when it should not move, and cause improper filter-wheel positioning. There were numerous improvements: [a] controller-internal-software upgraded from V. 3.20 to V. 4.0, [b] monochromator-stepper-motor- controller-pcb-software upgraded from V. 3.20 to V. 3.30, [c] monochromator-chopper- controller-pcb-software upgraded from V. 3.10 to V. 3.30 (partially based on Biggar's suggestion to continuously monitor the chopper position when in DC mode), [d] additional grounding wires added to the control cable, [e] separate +5V power supply added to the stepper-motor-control- pcb, [f] new software, V. 4.10. LaMarr loaded the new software, and set the unit up and checked it. The filter wheel for the repaired system did not operate, which Optronic replaced and we installed. LaMarr and Spyak spectrally calibrated the system to within 0.05% of wavelength specification using mercury and krypton sources. The agreement in transmittance of a filter measured before and after the repairs is better than 1%, except in the cutoff and cuton regions of the filter where spectral accuracy and precision play a significant role. LaMarr and Spyak determined the Optronic monochromator had a significant drift in its signal output. After further experimentation, they determined the drift is due to mechanical stresses induced by the thermal expansion and contraction during use. LaMarr and Spyak have attempted to eliminate these stresses, and the system now appears to be stable to about 0.5%. LaMarr also checked spectral errors due to inserting and removing the slits and found these errors to be about 0.02%. In preparation for his Japan trip, Biggar used the system to measure the spectral-filter transmittance for each band of the VNIR transfer radiometer. He and LaMarr measured all of the filters with both narrow (about 0.25-nm FWHM resolution) and wider (about 1-rim FWHM resolution) slits.

LaMarr and Spyak measured the Che radiometer FOV, and LaMarr estimates the error in blacklab panel calibrations due to the FOV to be less than 1%. LaMarr designed and constructed a mount for our Barnes MMR to measure its FOV and he and R. Parada measured the MMR FOV for one of the SWIR channels. The results of these measurements show the MMR has out-of-field problems due to stray light when used for blacklab panel calibrations. LaMarr estimates that the error in a reflectance panel calibration due to the out-of-field problems to be in the 3-5% range.

LaMarr measured the polarization effects from Algodon and Halon. Measurements were made with four different incident light polarization combinations at 450, 700, and 1040 nm. No significant level of polarization was noted in the reflected light from either sample. LaMarr measured the stray light from the newly constructed light shield and noted that it is not a problem. Further measurements of an eight-month old Algodon sample in the VNIR showed that the percent change in the sample's reflectance was 0.1 % for most view angles, increasing to 0.5% at an 80 degree view angle. LaMarr began characterizing the interference filters for the blacklab.

**Algorithm and Code Development:** Currently, several algorithms exist to perform our calibration work. The RSG has applied these algorithms as FORTRAN programs which are neither user friendly nor efficiently linked together into a single package. The task objective is to convert these existing codes into ANSI standard C in a user-friendly package with rules-based decision making in the package. The group is now also involved in the atmospheric correction of ASTER data in the solar-reflective portion of the spectrum

Biggar and Kingston installed and configured ERDAS Imagine version 8.1, and later 8.2, for Solaris. C. Gustafson began evaluating Imagine for its use in our calibration procedures. Biggar and Crowther installed and configured AutoCAD version 12 on our Sun network running under Solaris 2.3. This will be used for designing new instruments and new laboratory apparatus. Biggar installed and tested Ethernet, SCSI, and GPIB controllers in the two new, rugged field computers. S. Reeker began creating a home page for the RSG and connecting pages for faculty to the Optical Sciences Center home page.

Thome continued work on the test data set for the ASTER VNIR/SWIR atmospheric correction. The ATBD for the atmospheric correction was revised. Thome modified the water vapor model code to more closely simulate the geometry of MODTRAN and to allow arbitrary temperature, pressure, and water vapor profiles. He used MODTRAN output to examine which bands between ASTER and MODIS had the smallest differences in band-integrated, top-of-the-atmosphere radiance for a given set of atmospheric conditions.

Parada began incorporating a new wave-slope model into the successive orders radiative transfer code. He also examined methods for determining the applicability of the radiance-based and reflectance-based calibration approaches over a water target.

Kingston attempted to determine the cause of our degraded Ethernet capability through the Spread Spectrum radio link which provides computer communications between our off-campus offices and the University Ethernet. He performed status monitoring and reconfiguration and studied the radio link performance for a three day period. The results of these tests indicate that the link is sporadic making some access to external E-mail services available. Kingston met with B. Decker of the University's Telecommunications Department at CCIT to test all possible frequencies of the antennae. Kingston began investigating costs involved with installing Frame Relay service to our office which should be more reliable. He installed nameserver software on the network to allow for delivery of internal E-mail when the our radio link is not operating.

**Field Experiments:** The objectives of the field experiments are to test new equipment, determine needed improvements, test retrieval algorithms and code, and monitor existing satellites in much the same way as we shall for EOS sensors,

Gustafson continued developing the manuals for the Cimel solar radiometer and ASD spectroradiometer. C. Deschappelles and Gustafson determined the Cimel solar radiometer began malfunctioning again because of an internal clock problem. They also collected Reagan and Cimel solar radiometer data concurrently to test the Cimel system. Gustafson and K. Thome were shown by C. Laumann how to set up and operate the solar aureole camera.

Gustafson ordered and received a carrying case for the ASD spectroradiometer and purchased a tripod for the system. She continued evaluating the ASD and investigated the

possibility of replacing the system's fiber optic cable with a longer one to simplify the use of the system for surface reflectance measurements.

K. Thome completed the SPOT calibration for the October 1994 White Sands trip. Gustafson and Thome completed both the Level 0 and Level 1 calibrations of Landsat-5 TM using the October 8 data from White Sands.

Reeker and Thome made arrangements for the April White Sands trip and the April Lake Tahoe trip. LaMarr calibrated the reflectance panels used for all of the trips. Burkhart fabricated parts for the new reflectance yoke in preparation for the March-April White Sands campaign. Nelson, Spyak, and Thome tested the new yoke and Nelson adjusted the system based on this test. We received two polycorders and accessories and two additional Exotech radiometers for use in field measurements.

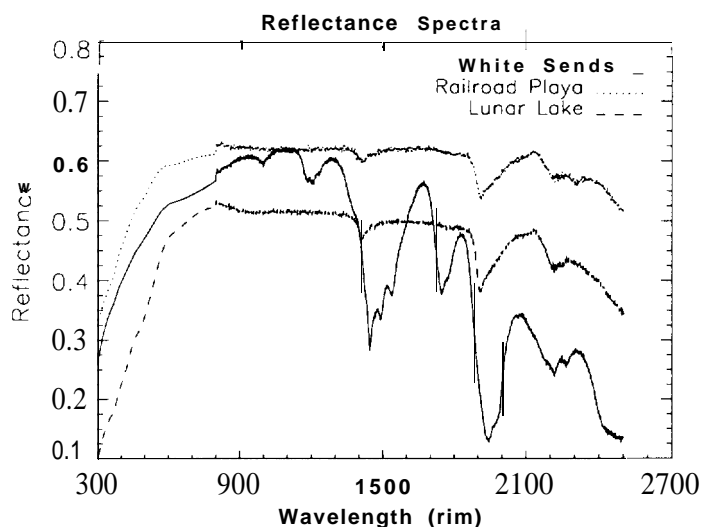
Surface samples from Lunar Lake and Railroad Valley were given to T. Zhao of the OSC Measurement Laboratory to determine their hemispherical, spectral reflectance but no results were obtained because of instrument problems. The samples were then given to M. Jacobson, Optical Data Associates. The results of these measurements are shown in Figure 3. The White Sands samples were collected from Chuck Site during our May, 1994 campaign. The Lunar Lake and Railroad Valley samples were collected by Slater during a visit to the area in October, 1994.

Several samples were collected from each site and measured but for clarity only one plot for each site is provided here.

The plot selected in all cases was that spectra which had the highest reflectance for each site. From the figure it is clear that all three sites have high reflectance values in the VNIR.

The reflectance for White Sands falls off at longer

wavelengths. The spectral **Figure 4** Results of spectral reflectance measurements of vicarious calibration site samples



reflectance for Lunar Lake and Railroad Valley are flat throughout most of the wavelength region shown whereas White Sands is much more variable. Even though Railroad Valley has the highest reflectance of the samples shown here, it also displayed the greatest variability in spatial homogeneity.

Burkhart completed three Exotech dark covers. Nelson began designing a box for transporting our barium sulfate reflectance panels.

C. Gustafson continued looking at the cross-calibration between SPOT and Landsat using the October 8-9, 1994 data set. Preliminary results are favorable. She developed software to look at the laboratory calibration of the solar radiometers using the 40-inch spherical-integrating source. The results were not good so Gustafson has begun looking for probable causes for the problem. She and LaMarr measured the filter transmittance of the interference filters for our 10-channel manual solar radiometer. C. Deschappelles showed Gustafson how to process data from this instrument.

Parada supervised the completion of the aircraft sensor mount gimble for use in our radiance-based calibrations. He tested the installation of the mount in the Cessna-180 used for the June Lake Tahoe experiment. The mount is designed to hold one of either our MMR or Exotech radiometers, the Spectron SE-590 spectroradiometer, the VNIR CCR, and our ASD spectroradiometer. Parada constructed new leads for the Spectron SE-590 for use with a PC and modified our data collection software to run on a PC. He modified the VNIR CCR software to also operate the MMR or Exotech for aircraft-based data collections. Parada purchased an uninterruptible power supply for use in aircraft-based data collections.

Brownlee, Crowther, Gustafson, LaMarr, Nelson, Spyak, and K. Thome travelled to White Sands from March 30 to April 4 to attempt calibrations of SPOT-2, SPOT-3, and Landsat-5. They were accompanied on the trip by S. Schiller and C. Plender of South Dakota State University and J. Luvall of MSFC. Thome processed the data for the SPOT-2 and SPOT-3 calibrations. The weather for the Landsat-5 overpass was not good enough to attempt a calibration.

Biggar, Parada, Scott, Sicard, Slater, and Thome travelled to Lake Tahoe from April 18 to April 26 for a joint campaign with other ASTER team members from JPL (A. Abtahi, S. Hook, G. Hoover, A. Kahle, A. Morrison, F. Palluconi, and J. Schieldge). The purpose of the

field work was to attempt vicarious calibrations of the thermal bands of ATSR-1 and Landsat-5 and the TIMS airborne sensor. The trip was also used as practice for anticipated collaborative field campaigns for the post-launch radiometric calibration of ASTER and validation of ASTER data products.

Biggar, Gustafson, LaMarr, Nelson, Parada, Slater, and Thome travelled to Ivanpah playa and Lake Tahoe from June 18-24 for an airborne-sensor calibration campaign. Parada coordinated and planned all activities at Lake Tahoe and the activities of the RSG's airborne equipment at Ivanpah. Thome coordinated the ground activities at Ivanpah. The goal of the Lake Tahoe portion of the trip was to determine radiance levels over the lake which will be used as a vicarious calibration target by the RSG for SeaWiFS. In addition, reflectance- and radiance-based calibrations of AVIRIS and HYDICE, were conducted using the Ivanpah data.

**Faculty, staff, and students:** The personnel presently associated with the RSG are as follows. Faculty: Biggar, Slater, Spyak, and Thome. Staff Burkhardt, Kingston, Nelson, and Reeker. Students: Brownlee\* (Ph.D.), Crowther\* (Ph.D.), Deschappelles (MS), Gustafson (Ph.D.), LaMarr (Ph.D.), Parada\* (Ph.D.), Scott\* (Ph.D.), and Walker\* (Ph.D.). Those with an asterisk following their names have passed the Ph.D. Preliminary Examination and are mainly working on their Ph.D. research. Brownlee and Crowther have NASA Fellowships under the Graduate Student Researchers Program, Parada has a NASA Global Change Fellowship and Deschappelles has a fellowship from the US Government. Walker is self-supported, leaving three graduate students supported by this and other contracts.

Rob Kingston joined the group, on a half-time basis, in January as a software engineer and programmer. He will help write software for controlling equipment in the laboratory for spectral measurements and for reflectance and FOV measurements in the blacklab. He will also help with network and computer system administration. A visiting French student, Michael Sicard, from the University of Strasbourg, joined the group in February. He worked with the group for 5 months assisting K. Thome with optical depth measurements in the SWIR using both our ASD spectroradiometer and the RSG developed SWIR spectroradiometer. C. Deschappelles completed her Master's degree in May and has since left the group to work for the US Government.

## **Publications**

During the past six months the following paper was published in the Japanese Journal of Remote Sensing:

### **Radiometric calibration of ASTER data**

P.N. Slater, K.J. Thome, K. Arai, H. Fujisada, H.H. Kieffer, A. One, F. Sakuma, F.D. Palluconi, Y. Yamaguchi

#### **ABSTRACT**

*Preflight and in-flight radiometric calibration plans are described for the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which is a high spatial resolution imaging spectroradiometer. It is designed for the remote sensing from orbit of land lakes, coastal and ocean surfaces, and clouds, and is expected to be launched in 1998 on NASA's EOS AM-I Spacecraft. ASTER comprises three subsystems which acquire images in three separate spectral regions." the visible and near infrared (VNIR), the shortwave infrared (SWIR), and the thermal infrared (TIR). The absolute radiometric accuracy is required to be better than 4% for VNIR and SWIR radiance measurements, and 1 K to 3 K, depending on the temperature region from 200 K to 370 K, for TIR temperature measurements.*

*ASTER will be calibrated in the laboratory by reference to sources traceable to NRLM and NIST standards and through the use of transfer radiometers. Partial aperture on-board calibration systems will be used in the solar-reflective range and an on-board full aperture blackbody source will be used in the infrared. An important independent source of calibration data will be provided through the in-flight radiometric calibration of ASTER by reference to well-characterized scenes.*

*This paper very briefly describes the calibration specifications for ASTER, the on-board calibration systems, the preflight and in-flight calibration procedures to be used, and suggests a method for combining the results of the various calibration inputs.*

During the past six months the following papers were accepted for publication in the Journal of Atmospheric and Ocean Technology:

### **Vicarious radiometric calibrations of EOS sensors**

P.N. Slater, S.F. Biggar, K.J. Thome, D.I. Gellman, P.R. Spyak

#### **ABSTRACT**

*Four methods for the in-flight radiometric calibration and cross calibration of multispectral imaging sensors are described. Three make use of ground-based reflectance, irradiance, and radiance measurements in conjunction with atmospheric measurements and one compares calibrations between sensors.*

*Error budgets for these methods are presented and their validation is discussed by reference to SPOT and TM results and shown to meet the EOS requirements in the solar-reflective range.*

## **Suggestions for radiometric calibration coefficient generation**

P.N. Slater and S.F. Biggar

### **ABSTRACT**

*The great emphasis that studies of global change have placed on accurate absolute radiometric calibration of satellite sensors has lead to the development of many new on-board and vicarious calibration techniques. With the launch in 1998 of the first Earth Observing System (EOS) sensors, calibration scientists will, for the first time, be confronted by a large number of calibration coefficients for each band of each sensor obtained using these different techniques. The question arises: what is the best way to combine these coefficients in order to maximize the accuracy of sensor calibration as a function of time?*

*This paper discusses the problem and suggests procedural criteria followed by a procedure for calibration-coefficient generation. Emphasis is placed on the use of on-board results in an on-line production of calibration coefficients and the modification of these coefficients, at perhaps three-month intervals, by reference to vicarious calibration results obtained during that period. Reference is made to the calibration of SPOT as a first simple example of such an approach.*